5.1 Agricultural Technology Development

Research and technology development have been the foundation of impressive productivity gains in the agricultural sector. The ability of the sector to conserve natural resources and protect the environment depends, in part, on the technologies used. Agricultural research is the source of new technologies, and important new technologies have emerged that may benefit the environment if adopted. Many factors— including public policies, profitability, and agronomic factors—affect technology development, adoption, and diffusion.

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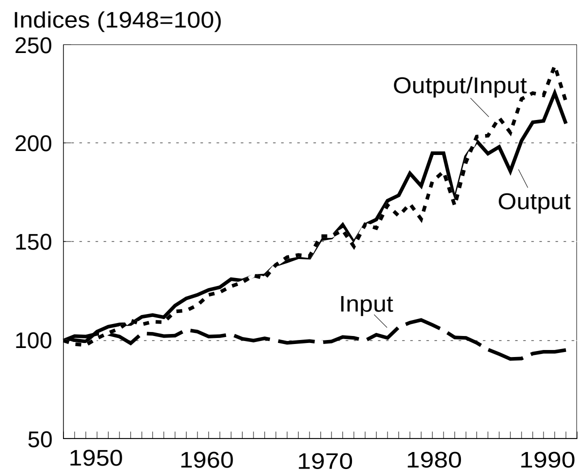
Research and technology development have been the foundation for productivity gains in the agricultural sector, averaging 1.8 percent per year during 1948-93 (see box, “Agricultural Productivity,” p. 224, and fig. 5.1.1). Growing concerns for the environment have expanded the priorities for U.S. agriculture. Many technologies being developed have the potential not only to increase farm productivity but also to reduce the environmental and resource costs sometimes associated with agricultural production. These include technologies that conserve land and water by increasing yields with the same or fewer inputs and technologies that protect environmental quality, such as pest- and disease-resistant crops that require fewer chemicals.

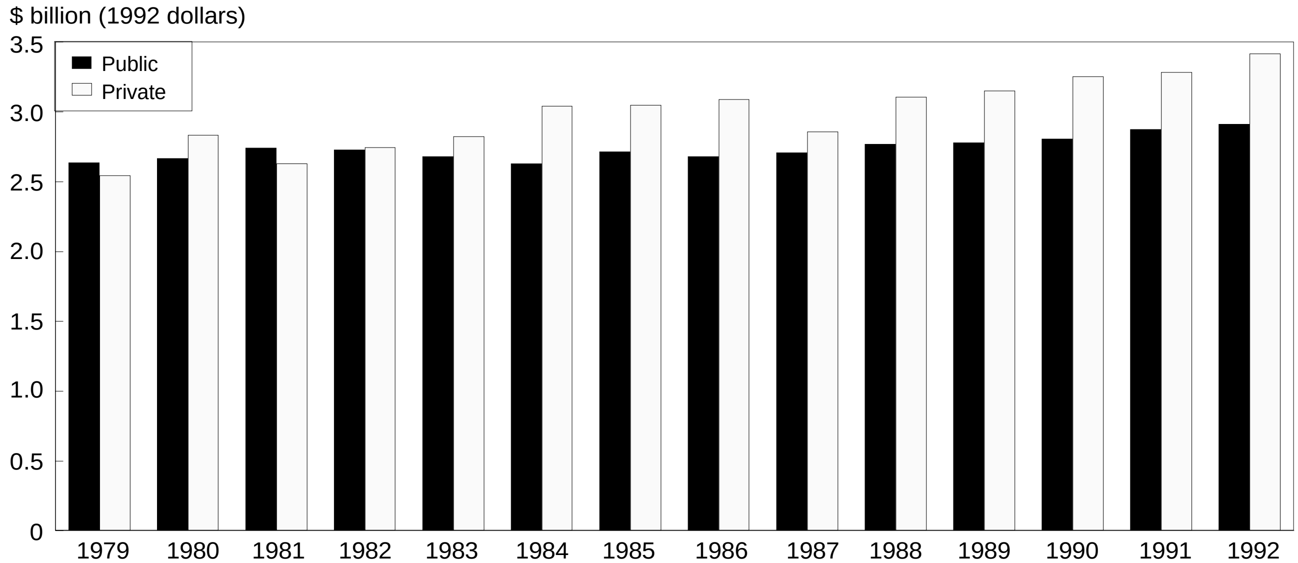
Two forces guide technological development. The first is “demand-pull,” where the needs of the marketplace create the demand for a product. Both public and private-sector scientists, inventors, and entrepreneurs often seek to meet this demand. The second force is “supply-push.” Here the impetus for development comes from scientists and inventors who find a new and valuable technology. This technology can then be introduced into the marketplace. Both forces (singly and together) produce important and

Figure 5.1.1--Productivity growth in U.S. agriculture, 1948-93



Source: USDA, ERS estimates.

Figure 5.1.2--Agricultural research funding, 1979-92



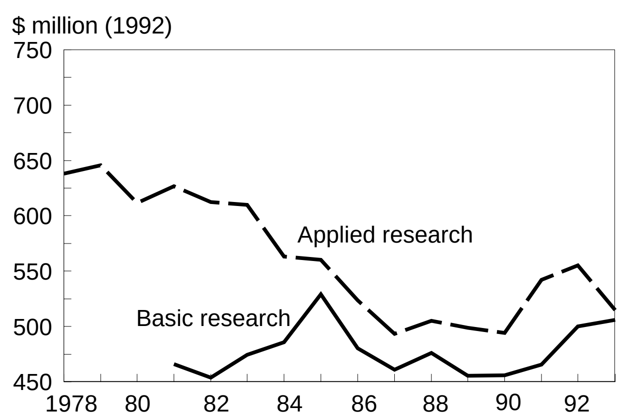
Source: USDA, ERS, based on Current Research Information System; and Klotz, Fuglie, and Pray,1995.

useful technologies, and the government can use both to encourage innovations that foster environmental quality and resource conservation. Policies such as environmental regulation can boost the demand-pull forces for environmentally benign technologies. Other government policies can foster supply-push forces for the desirable technologies. These policies include funding research and development, technology transfer activities, and efforts to understand and facilitate technology adoption.

The two major players in the agricultural research and technology development system are the public sector and private industry. After World War II, the public sector was the primary supporter and conductor of agricultural research. In recent years, the private sector has become a major contributor to the development of new agricultural technologies. Private-sector spending for food and agricultural research now exceeds agricultural research expenditures by the public sector (Fuglie and others, 1996; Huffman and Evenson, 1993; Klotz and others, 1995; and Pray, 1993). Private-sector agricultural research expenditures are estimated to have increased from $2.5 billion in 1979 to $3.4 billion in 1992 (fig. 5.1.2) (Klotz and others, 1995). Public-sector expenditures were $2.9 billion in 1992 (Fuglie and others, 1996).

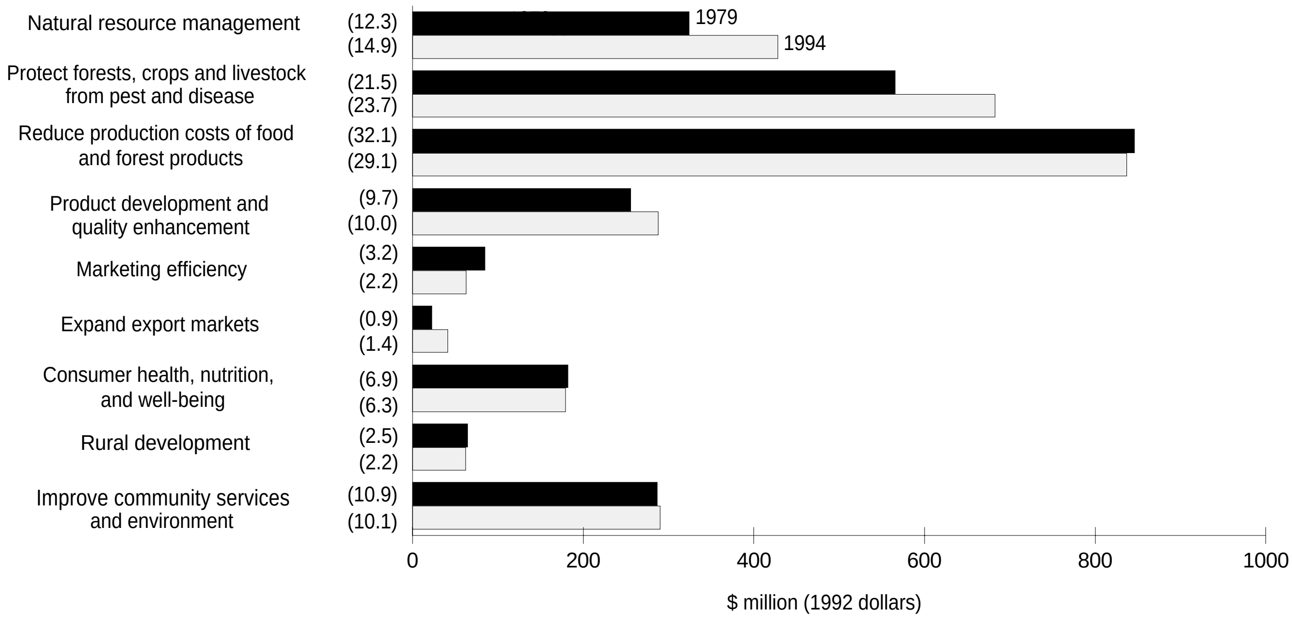
Public-sector and private-industry research differ in their focus. Public scientists conduct more basic or fundamental research, which seeks a fuller understanding of phenomena without specific applications to products or processes. Basic research is the foundation for all other research efforts and outcomes. Approximately 47 percent of public research funds are allocated to basic research efforts (fig. 5.1.3), which has higher rates of return than applied research. While the payoff to society of investing in basic research is high, the results of such research generally cannot be appropriated. The gains benefit society as whole, therefore the private sector has little market incentive to conduct basic or pre-technology research. Only 15 percent of

Figure 5.1.3--USDA expenditures for basic and applied research, 1978-93



Estimated for 1992, and proposed for 1993.
Source: USDA, ERS, based on National Science Foundation, 1992.

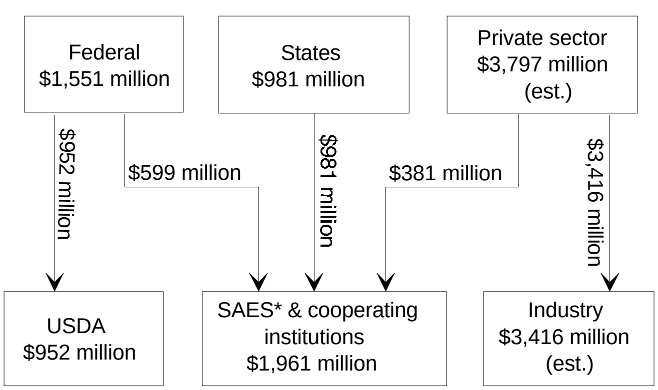
Figure 5.1.4--Allocation of public funds for agricultural research, 1979 and 1994



Numbers in parentheses indicate each item's percentage of public funds for agricultural research that year.
Source: USDA, ERS, based on USDA, Current Research Information System data, 1979-95.

private-sector funds are used in basic research (USDA, 1993; Agricultural Research Institute, 1985). Likewise, there is limited incentive for private-sector research that improves government or consumer decisionmaking as regards, say, the relationship of agriculture to natural resources, global climate change, ecosystem loss, human nutrition and diet, and

Figure 5.1.5--Sources and flows of funding for agricultural research in 1992



*SAES are the State Agricultural Experiment Stations; Cooperating institutions include the 1890, forestry, and veterinary schools

Sources: USDA, ERS, based on USDA, Current Research Information System, 1979-95. Private sector/industry expenditures are from Klotz, Fuglie, and Pray, 1995.

food safety (for the distribution of public-sector research, see fig. 5.1.4). Private research focuses on bringing products to market, and generally must contribute to the overall profitability of the firm. More than 40 percent of private agricultural R&D expenditures are for product development research. In contrast, less than 10 percent of public agricultural R&D expenditures are applied to product development research. Therefore, a combination of public-sector and private-sector research is important in developing new agricultural technologies.

Public Sector Research and Development

Public agricultural research involves a unique partnership between the Federal Government (chiefly USDA) and the States. USDA and the State Agricultural Experiment Stations (SAES) together conduct almost $3 billion of research (Fuglie and others, 1996). USDA conducts about $950 million worth of research in-house through its research agencies, primarily the Agricultural Research Service, the Forest Service, and the Economic Research Service. The SAES and cooperating institutions conduct about $1.9 billion worth of research, making them the largest performer of research in the public sector. USDA pays for about $1.5 billion of total public research, the States less than $1 billion, with additional funds supplied by the private sector (fig. 5.1.5). USDA uses several funding instruments to provide research money to States. One instrument is ***formula funds***, allocated in block form to States based on rural population and number of farms. ***National Research Initiative competitive grants*** are allotted according to peer review. ***Special grants*** are awarded by Congress, whereas other USDA ***contracts, grants, and cooperative agreements*** are determined by USDA. (See Fuglie and others, 1996, for a more detailed description of these mechanisms.) Since 1983, competitive and special grants have grown in importance as funding sources and reached 13 percent and 16 percent in 1993. Formula funds declined from 74 percent of USDA funds in 1983 to less than 53 percent in 1993. Cooperative agreements stayed around 17 percent.

Because State-level research is so important, and these instruments fund research differently, the merits of these instruments are being discussed in the political arena. Traditionally, State-level research has fostered a decentralized research approach as well as geographically specific applied research. In the early 1970's, some critics contended that agricultural research had become too applied, moving too far from basic biological research (National Research Council, 1992). These critics called for greater peer review and competition for research funds, as well as a shift to more basic biological research and away from commodity-specific applied research. This shift included moving from formula funding to competitive grants. Behind this recommendation was the belief that biotechnological breakthroughs based on basic biological research were needed to maintain historical rates of agricultural productivity growth. Continuing to rely on formula funds, which fostered geographically specific commodity research, might not generate the needed breakthroughs.

These recommendations have themselves met with criticism. Buttel (1986) warned that the shift toward competitive grants might narrow the focus of agricultural research in two ways. First, the research problem areas addressed might be narrowed and public-sector research would then be redirected toward profit-maximizing goals of private biotechnology firms. The public sector would move

Agricultural Productivity

From 1948 to 1993, aggregate U.S. agricultural output more than doubled, growing at an average annual rate of 1.7 percent (fig. 5.1.1). In contrast, aggregate input use (the sum of land, labor, machinery, chemicals, etc.) averaged a slight decrease (-0.1 percent per year). Thus, the growth in output was due to increased productivity. Output per unit of input, indicated by the multifactor productivity index, grew by an average of 1.8 percent per year during 1948-93. This was above the 1.1-percent average rate in the private nonfarm economy.

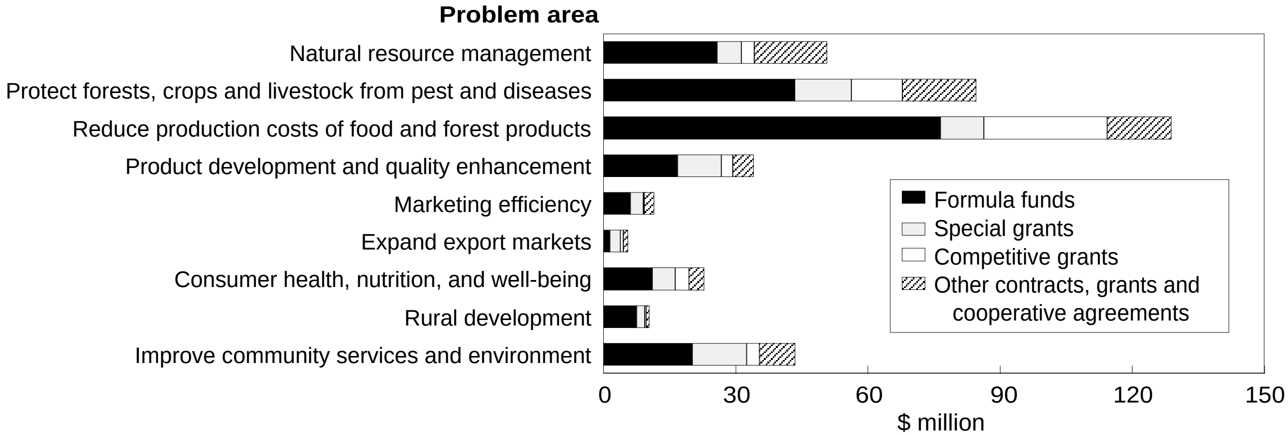
Growth in inputs is typically identified as the driving force of economic growth. In agriculture, the driving force has been productivity growth. The ability to increase production significantly using the same or fewer aggregate inputs could not have occurred without the development of new agricultural technologies—higher yielding varieties, improved livestock breeds, and innovative tillage and irrigation equipment.

The relatively stable aggregate input level disguises larger shifts in individual inputs: purchased (intermediate) inputs changed and capital increased while labor input declined. Agricultural producers held down production costs by substituting capital, primarily durable equipment, and intermediate inputs for labor. This is clear from labor's decreasing share in total input cost. Labor's cost share (including the imputation of self-employed labor) fell from 41 percent in 1948 to 23 percent in 1993. In contrast, the share of capital in total cost increased from 9 percent in 1948 to 28 percent in 1993. Intermediate inputs accounted for approximately 50 percent of the total cost of agricultural inputs in both years.

The stable share of total input cost for intermediate inputs disguises significant shifts within this broad category during 1948-93. While intermediate inputs in aggregate increased at an average rate of 1.3 percent per year, pesticide consumption increased an average of 6.1 percent per year; and feed, seed, and livestock purchases, 2.2 percent per year. In contrast, fertilizer increased only 1.7 percent, and energy inputs less than 1 percent (0.8 percent) annually.

Among other input categories, labor in agriculture decreased at an average annual rate of 2.7 percent over the postwar period, with greater reductions occurring in self-employed labor than in hired labor. Capital input to agriculture (particularly durable equipment) increased dramatically in the immediate postwar period, but the average annual rate of growth over the entire 1948-93 period was less than 1 percent (0.7 percent). Service flows from farm real estate—land and service buildings—declined modestly.

Figure 5.1.6--USDA funds to SAES and other institutions, 1993



Source: USDA, ERS, based on USDA, Current Research Information System, 1979-95.

away from emphasizing social rates of return, which would reduce the value of public research to society as a whole. While natural resource and environmental research has a high value to society, it is seldom profit-maximizing. Second, declines in formula funding could possibly skew the geographic distribution of USDA research funds granted to individual States. States with strong programs in molecular and cellular biology would fare well under the new system, but Experiment Stations further from the frontier of biological research might be starved for funds. The choice of a funding mechanism can thus have significant consequences for natural resource and environmental research.

Different instruments have, historically, focused on different research goals (fig. 5.1.6). For example, competitive grants are concentrated on two goals—control of pests/diseases and reduced production costs. Special grants and cooperative agreements are used to fund a greater portion of research on natural resource, environmental, food safety, and rural development issues.

Because environmental protection and resource management are often site-specific, concentrating funding in fewer States may leave certain States without adequate funds to conduct research effectively and meet their needs. However, concentrating funds in States with strong research programs could increase the likelihood of finding solutions to various resource and environmental problems. In evaluating the degree to which funding instruments affect the geographic distribution of funds across States, Frisvold and Day (1992) showed that (1) formula funds are the most evenly distributed across States, (2) competitive grants are the most unevenly distributed, and (3) special grants and cooperative agreements lie between.

Therefore, competitive grants (as predicted by Buttel) are concentrated among fewer SAES and are used to fund a narrower set of research objectives than other instruments. However, the emphasis on competitive grants has not significantly shifted the geographical or topical distribution of total USDA funding of SAES. Distributional curves for overall funds are virtually unchanged from 1983 to 1992. Furthermore, while the distribution of research funds among research categories is very different for formula and competitive grants, total USDA funding closely matches that of formula funds. There are two reasons for this. First, competitive grants comprise only 11 percent of USDA funds to SAES. Second, special grants and cooperative agreements counterbalance the effect of competitive grants. Therefore, shifts in funding method appear not to have greatly affected natural resource and environmental research at SAES and cooperating institutions thus far. However, a significant shift toward competitive grants could limit the traditional sources of funding for this research, unless the allocation process could be changed to increase the priority of resource and environmental research.

Private Research and Development

Private industry has been moving into new areas of research—specifically, biological and chemical technologies such as agricultural chemicals, plant breeding, and animal health. Private-sector expenditures in these research areas increased from

Figure 5.1.7--Private agricultural research by industry

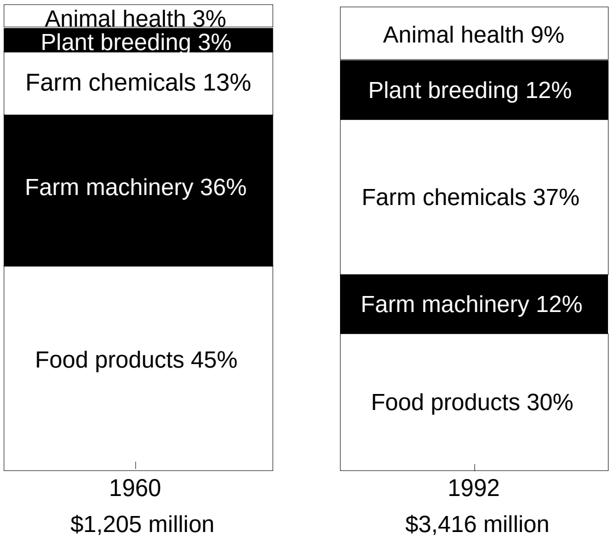


Figure in 1992 dollars.
Source: USDA, ERS, based on Klotz, Fuglie, and Pray, 1995.

19 percent of agricultural research in 1960 to 58 percent in 1992 (fig. 5.1.7). Historically, the public sector has conducted yield-increasing agricultural research, especially in plant breeding, and private sector research has focused on "downstream" technologies, such as food processing and farm machinery. Private-sector researchers have new incentives to expand agricultural R&D, albeit into areas that are more commercially oriented than public research.

Scientific advances in biology in the past 20 years, coupled with government policies and regulations, expanded private-sector incentives for conducting agricultural research. Public investments in basic research created new technological opportunities for private research. Scientific breakthroughs, such as the development of biotechnology applications, helped facilitate agricultural research. For example, tissue cell culture reduced the time required for developing new plant varieties. Also, gene transfer technologies enabled researchers to tailor crops for specific uses, such as crops that are resistant to disease, pests, or harsh environmental conditions; that are more nutritious; or that improve food processing.

Besides scientific advancements, intellectual property rights (IPR's) were strengthened for new plant varieties and biological inventions. IPR's have encouraged private research by allowing innovative firms to capture a greater share of the benefits from research (discussed more below). Regulations are often associated with increased product development costs, as has been the case with pesticide regulation and the development of pesticides (Ollinger and Fernandez-Cornejo, 1995). However, regulation can also stimulate private-sector research that is beneficial to private industry. For example, regulations attempting to protect the environment, food safety, and nutrition have encouraged research on technologies that are more compatible with these regulatory goals.

Role of Intellectual Property Rights

To foster research and innovation, the results from these efforts must be appropriable. The Patent Act of 1790 established a system of property rights protection to encourage manufacturers and inventors to develop new industrial inputs and consumer products. However, the principal contribution of this patent act to agriculture was the protection offered for mechanical and chemical inventions. Biological inventions were considered products of nature and were not patentable. Therefore, appropriating the gains from technological advances in plant breeding was difficult. Simply possessing a biological invention provided the means to reproduce it. Producers of a new plant or animal could only profit from their invention once, even though it could be used for generations. The development of hybrid seed technologies in the 1920's changed this because hybrid crops reproduce at decreasing yields, and thus, require farmers to repurchase seed every year. Private-sector plant breeding efforts then focused on hybrid seeds.

The extension of IPR's to new plant varieties and biological inventions, including the development of biotechnologies, has stimulated private companies to invest in plant breeding. The Plant Patent Act of 1930 and the Plant Variety Protection Act (PVPA) of 1970 established plant breeders' rights for new plants and plant varieties (see box, "Intellectual Property Rights"). In 1980, a Supreme Court decision (*Diamond v. Chakrabarty*) authorized the use of Utility Patents for biological inventions, specifically microorganisms. Several recent decisions by the Patent and Trademark Office broadened the use of Utility Patents for plants (ex parte Hibberd in 1985) and animals (ex parte Allen in 1987). As a result, private-sector research expenditures for plant breeding have increased from $6 million in 1960 to $400 million in 1992 (Klotz, Fuglie, and Pray, 1995; Fuglie, Klotz, and Gill, 1995). Nearly 70 percent of private-sector plant breeding research expenditures in 1989 was for corn, vegetables, and soybeans. Private

Intellectual Property Rights for New Plant Varieties and Biological Inventions

Utility Patents
Utility Patents are administered by the Patent and Trademark Office (PTO) of the U.S. Department of Commerce and grant ownership of new inputs and products for 20 years. Biological inventions were not patentable until 1980 when a decision by the Supreme Court in *Diamond v. Chakrabarty* authorized the use of Utility Patents for microorganisms. In 1985, the PTO's Board of Appeals and Interferences approved the use of Utility Patents for plants, and in 1987, for animals. Although Utility Patents offer owners the strongest form of protection for new plant varieties, they are more difficult to acquire compared with other options for obtaining plant breeders' rights.

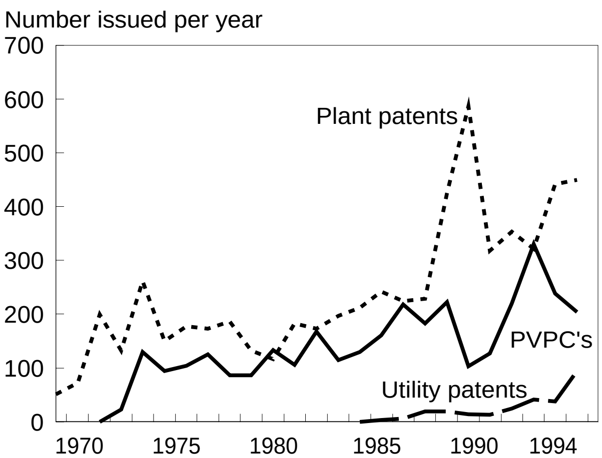
Plant Patents
The Plant Patent Act amended the Patent Act of 1970 and provided plant breeders protection for 17 years for asexually reproduced plant varieties. Specifically these include fruits, nuts, and ornamentals, but exclude tuber crops. As with Utility Patents, PTO administers Plant Patents.

Plant Variety Protection Certificates (PVPC's)
The Plant Variety Protection Act of 1970 created PVPC's, which established plant breeders' rights for new plant varieties produced from seed, particularly field crops. PVPC's are awarded for new plant varieties determined to be distinct, uniform, and stable. A 1980 amendment extended coverage to vegetables. Amendments in 1994 restricted farmer rights to resell protected seed, provided protection for tuber crops, and extended property rights protection from 17 to 20 years. A provision was also added to protect plant breeders from cosmetic infringements or superficial changes in the appearance of protected plant varieties that do not increase yield or value. A 1995 Supreme Court decision, *Asgrow v. Winterboer*, further restricted farmer rights to resell protected seed. The U.S. Department of Agriculture administers PVPC's.

Source: USDA, ERS, based on Fuglie and others, 1996.

firms have also reacted to changes in IPR's by investing heavily in biotechnology techniques. Expenditures on agricultural biotechnology research rose from almost nothing in the mid-1980's to $595 million in 1992.

Figure 5.1.8--Intellectual property rights issued for new plant varieties, 1970-94

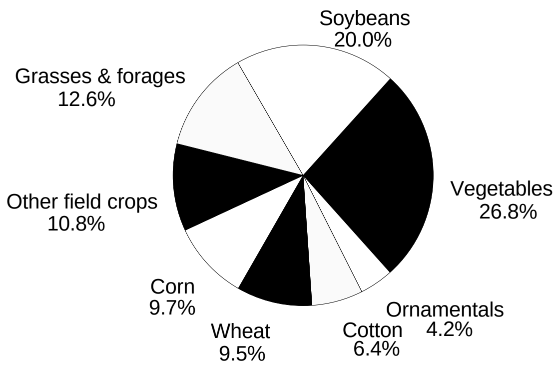


Source: USDA, ERS, based on Agricultural Marketing Service, Patent and Trademark Office data.

The number of Plant Patents, Plant Variety Protection Certificates (PVPC's), and Utility Patents issued over the last 25 years has risen (fig. 5.1.8). The PVPA stimulated the development of new field crop varieties. By the end of 1994, 3,306 PVPC's had been issued for new crop varieties. The number of PVPC's issued for new varieties of field crops, grasses, and vegetables climbed from 153 in 1971-74 to 992 in 1991-94. New soybean, corn, and vegetable varieties accounted for 56 percent of total PVPC's awarded (fig. 5.1.9). The private sector owns approximately 87 percent of the total PVPC's issued. Oats was the only crop for which the public sector held a higher share of PVPC's. Utility Patents are the most difficult to obtain and have been awarded primarily for new biotechnology innovations, such as genetically engineered varieties. By December 1994, 324 Utility Patents had been issued for multicellular organisms. Of these, 286 were issued for new plants or plant parts and 38 were issued for animals. As with PVPC's, most Utility Patents were awarded to the private sector (Fuglie, Klotz, and Gill, 1995).

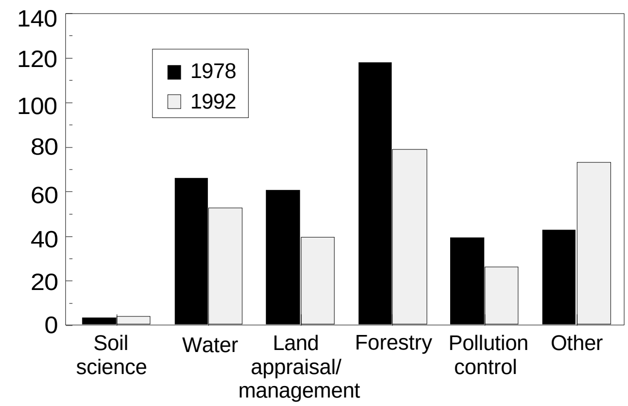
IPR's have encouraged the private sector to develop new agricultural technologies by enabling firms to capture a greater share of the commercial value of

Figure 5.1.9--Use of plant variety protection certificates issued in 1971-94 (3,306 in total)



Source: USDA, ERS, based on Fuglie and others, 1996.

Figure 5.1.10--USDA funding for in-house research on natural resources and the environment



Source: USDA, ERS, based on USDA, Current Research Information System, 1979-95.

their inventions. However, IPR's remain controversial since they can involve tradeoffs between competing objectives. The increased market power afforded to firms holding IPR's could result in higher seed prices. Scientific progress could also be hindered if IPR's slow the exchange of information on new technologies. Policies, such as cooperative research efforts between the public and private sectors and the licensing of new technologies by the public sector, can facilitate the transfer of technologies or information.

Natural Resource and Environmental Research

The increasing complexity of environmental problems is likely to heighten expectations of the agricultural sector. Agricultural research needs to find ways to minimize any negative environmental consequence of agricultural production, while preserving (and ideally increasing) yields. Public support of research on new technologies to conserve natural resources and enhance environmental quality is necessary because environmental resources are largely public goods, that is, goods for which there are few private incentives to protect or conserve (Ruttan, 1971). USDA helps determine which environmental and resource issues are of national importance. States conduct research to be used in national and regional priority setting, as well as in determining regional solutions for these issues.

USDA Natural Resource Research

Natural resource research concerns the use, management, and conservation of natural resources and the environment. USDA natural resource research was approximately 18 percent of the total research conducted by the Federal Government in this field during 1992.[1] Natural resource research funded by USDA research agencies fell between 1978 and 1992. However, the share of USDA research funds devoted to natural resource research remained steady from 1984 to 1992, between 33 percent and 37 percent.

USDA inhouse research subjects in natural resources and the environment include soil science, land appraisal and management, water, forestry, pollution control, and other (including interdisciplinary). Forestry (which includes research on new and improved forest products) was the largest recipient of funds, in both 1978 and 1992 (fig. 5.1.10). Soil science funding grew slightly. The most dramatic increase was in the category entitled "other," especially for interdisciplinary research, weather research, and remote sensing. This results, in part, from the Global Change Initiative. Funds for water, land assessment, pollution control, and forestry declined between 1978 and 1992. Interdisciplinary projects may have absorbed some of these research funds.

The proportion of total USDA natural resource research allocated inhouse declined from 81 percent in 1978 to 72 percent in 1991. Universities and research institutions outside USDA are conducting an

[1] Funding data are drawn from the Current Research Information System, Tables III and IV. Table III reports appropriations for the pertinent fiscal year, while Table IV reports fiscal-year obligations. Consequently, the numbers are best used together as a measure of relative trends, rather than absolute funding statistics.

increasing percentage of agency-funded natural resources and environmental research. Also, a growing percentage of funding is going to institutions other than SAES, such as other universities and research institutions, as USDA looks beyond the SAES system for partners in natural resource research.

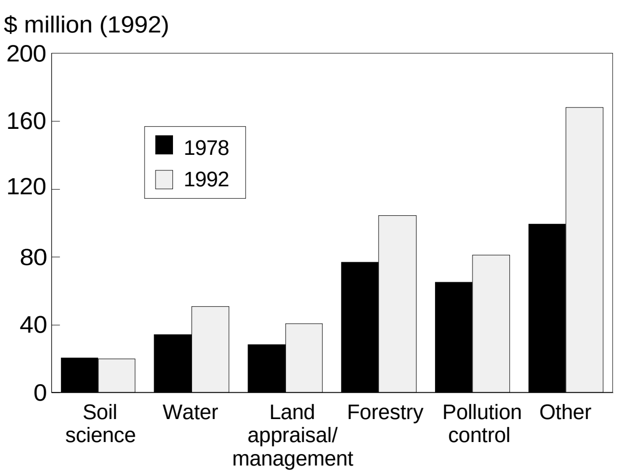
SAES Natural Resource Research

SAES and other cooperating institutions conduct the largest percentage of natural resource and environmental research. SAES receive funds from a variety of sources, including USDA agencies, State appropriations, product sales, and private industry. Between 1978 and 1991, SAES natural resource research funds rose substantially, surpassing USDA inhouse resource research in 1979.

Natural resource funding at SAES and cooperating institutions was spread relatively evenly among research areas (fig. 5.1.11). The category "other" was the largest recipient of funds, with the leading research problem areas being an interdisciplinary research category and the fish and wildlife category. Forestry was the next largest recipient of appropriations. Unlike USDA inhouse research, each research subject received increased funding over 1978-92.

State revenues have been an increasingly important funding source for natural resource research at SAES. After 1981, State appropriations to Experiment Stations rose steadily. By 1991, appropriations had increased almost 37 percent over the 1978 level, to more than $179 million. State funds have approached the level of inhouse funding by USDA, which suggests that the influence of State-level priorities may be increasing.

Figure 5.1.11--Funding at State agricultural experiment stations for research on natural resources and the environment



Includes cooperating institutions.

Source: USDA, ERS, based on USDA, Current Research Information System, 1979-95.

The impact of these trends on natural resource and environmental research is unclear. Increased activity at the State level suggests that more resources may be invested in applied work with a regional focus. Applied site-specific research is an important element of many resource-conserving agricultural techniques (integrated pest management, precision farming, nutrient management systems). On the other hand, certain environmental problems affect and are affected by agriculture on a larger scale. Such concerns as acid rain and nonpoint-source water contamination cannot easily be assigned to a particular State and may call for national efforts.

The returns to natural resource and environmental research are not easily measured, because many environmental goods and natural resources are difficult to value in themselves. While the appropriability of resource and environmental research is low for the private sector, the value of the resources is very high for society, suggesting a strong role for the public sector.

Adoption and Transfer of Green Technology

From society’s point of view, a technology that will conserve scarce resources or protect the environment should be brought to the marketplace and adopted by agricultural producers (if its benefits exceed its costs). The more efficient use of inputs and resources offered by new technologies benefits the farmer (lowered costs of production) and the public (conservation of resources and preservation of the environment, characteristic of “green” technologies). Developers will only bring new technologies to the marketplace if they are profitable and producers will use them only if the benefits outweigh the costs (see box, "Area Studies of Technology Adoption,” p. 250). Off-farm environmental benefits are generally not part of the developer’s or the producer’s calculation, so there will be less use of the technology than if the full benefits and costs to society were included. Despite the potential value to society, certain green technologies are not developed, adopted, or diffused widely. (*Adoption* refers to the decision by individual producers on whether to use a technology, whereas *diffusion* is the rate and extent of technology adoption over time.)

Area Studies of Technology Adoption

Between 1991 and 1993, USDA surveyed 10 major U.S. watersheds to gain a better understanding of the factors affecting the adoption of resource-conserving agricultural technologies. Also, the studies sought to clarify how these technologies affected resource use, production efficiency, and farm income. The studies collected data on farm production practices and natural resource characteristics, such as soil and land quality. ERS researchers used multivariate regression to analyze the effects of agricultural policies, resource attributes, and farm characteristics on farmers' decisions to adopt specific agricultural technologies designed to conserve environmental resources. (For the areas surveyed, see "Area Studies Project," in the appendix, p. 329.)

A consistent finding of this work is that natural resource characteristics are major determinants of technology adoption. The performance of resource-conserving technologies varied considerably from one farm to another, depending largely upon soil quality and climatic factors. While a new technology may help some farms to conserve environmental resources while maintaining or even increasing production efficiency, it may not be as effective on a neighboring farm with different resource conditions or cropping practices. For example, soil nitrogen testing was found to reduce chemical fertilizer use (without reducing crop yields) on fields with substantial organic nitrogen carryover from the previous cropping season (Fuglie and Bosch, 1995). However, on other farms without significant nitrogen carryover, soil testing did not affect fertilizer use. Another example was the adoption of no-till farming. By using no-till instead of a conventional tillage system, farmers can reduce soil erosion to a fraction of the previous rate. However, in some areas, climatic factors and soil conditions appeared to limit the viability of no-till farming. The results from these and ongoing analyses of the Area Studies data are helping to identify factors that may be constraining the more widespread adoption of resource-conserving technologies.

Technology Transfer Programs at USDA and SAES

Valuable technologies developed in the public sector will not always be marketed by the private sector. Therefore, USDA and the SAES work to bring useful technologies to the agricultural sector. Both groups transfer a variety of innovations, both shielded and unshielded (protected by IPR's or not). The Technology Transfer Act of 1986 greatly increased the ability of federally funded institutions to transfer successful technologies to the marketplace.

Table 5.1.1—USDA technology transfer activites, 1987-93

Year	Patents awarded	Patent license royalties	Active CRADA's[1]	Value of CRADA's[2]
	Number	*$1,000*	*Number*	*$ million*
1987	34		85	1.6
1988	28	97	48	8.7
1989	47	418	86	15.6
1990	42	567	104	18.9
1991	57	834	139	25.6
1992	56	1,044	160	30.0
1993	57	1,483	185	34.0
1994	32	1,426	212	61.3

[1] Cooperative Research and Development Agreements.
[2] Includes the value of USDA and private-sector resources committed to the CRADA's.
Source: USDA, ERS, based on Talent, 1994; and Watkins, 1996.

Cooperative Research and Development Agreements (CRADA's) are public-private agreements usually between the Federal Government and private industry. This mechanism allows USDA and SAES to transfer technologies, research results, and scientific resources (not money) to industry through joint research ventures. The cooperating firm can provide any of these resources, and can also transfer money to the Federal agency as part of a research agreement. Cooperating firms have the first right to any patented inventions resulting from the agreement (ARS, 1992). USDA has established more than 500 CRADA's, making it among the leading Federal agencies in this area (table 5.1.1). USDA provides basic scientific knowledge often unavailable to private industry, and receives insight into industry needs and resources, as well as shared fees and royalties.

Patents and licensing are another set of mechanisms used by USDA, as well as SAES. Public entities can patent inventions meeting the criteria of the U.S. Patent and Trademark Office. The institutions, such as USDA, can then grant an exclusive or nonexclusive license to a private company to use or market the invention. Exclusive licensing of patents often provides incentives for a company to develop a technology. Before federally funded institutions were allowed to grant exclusive licenses, companies were often unwilling to make the investments necessary to bring these inventions to the marketplace (ARS, 1993). USDA maintains publicly available lists of patents available for licensing.

Two institutions are primarily responsible for bringing ARS inventions and knowledge to the private sector. The ARS Office of Technology Transfer patents, licenses, and markets ARS technologies and negotiates CRADA's. To facilitate close cooperation between inventors and firms, ARS has patent advisors and technology transfer coordinators at laboratories throughout the country. A second group, the Technology Transfer Information Center, provides informational support to ARS through the National Agricultural Library. The center manages information ARS needs to set priorities for research programs and to patent and license new inventions. Center staff aide ARS scientists by finding other relevant research results inside and outside the agricultural sector. The center also provides information to the public on ARS research and inventions. One product of the center, TEKTRAN, is an electronic database containing more than 25,000 summaries of ARS research findings. The summaries include an interpretive summary in nonscientific language, a technical abstract, and information on the contact scientist.

One example of a successful USDA technology transfer is the Biosys/ARS partnership. Scientists at ARS developed a parasitic nematode that controls two serious corn pests, the corn earworm and the fall armyworm. Biosys (a biotechnology company) is commercializing this technology, which is expected to prevent crop losses totaling several hundred million dollars (ARS, 1994).

SAES and other university institutions also may have offices of technology transfer. These are generally used for shielded innovations. This office will determine the commercial prospects of research output. Generally, those innovations that are sufficiently developed will go through the patent and licensing process (Parker and Zilberman, 1993). If further research is needed, the university may pursue a CRADA. Unshielded innovations usually pass through the extension system for information transfers through conferences, publications, education, or training (Parker and Zilberman, 1993).

Adoption

The characteristics and availability of the green technology will largely determine producers' decision to adopt. Technologies that offer only marginal improvements to existing methods or are difficult or costly to use often diffuse slowly. Agro-ecological factors, such as soil type, water availability, and climate, may also limit the adaptability and profitability of new technologies. Some emerging agricultural biotechnologies may give farmers new alternatives and opportunities for maintaining productivity while following environmental regulations designed to reduce environmental costs. However, many new agricultural technologies are complex and require a much higher level of human capital and managerial skills than in the past, increasing the costs of their adoption. Certain technologies may be economically desirable over time, but require substantial capital investment (for example, certain precision farming technologies). All these factors may result in a green technology not being voluntarily adopted widely enough to meet environmental goals.

The Government can pursue two types of policies and programs that encourage the adoption of beneficial technologies. First, through regulation or taxation, the Government can increase the cost or ban the use of environmentally damaging or natural resource-intensive inputs. Second, it can offer financial or technical assistance to farmers who adopt the preferred technology. Each approach will affect the actual diffusion of the technology differently, as well as determine who will bear the cost.

USDA uses a variety of policies to promote environmentally beneficial technologies, including cost-sharing, technical assistance, and extension education (see box, "Developing a Green Technology"). Practices approved for cost-sharing by USDA usually yield long-term benefits and are practices that the farmer would not, or could not, soon undertake without financial and technical assistance. USDA currently has programs that provide cost-sharing and other funding to farmers who adopt practices that improve or enhance water quality (see chapter 6.2, *Water Quality Programs*). USDA also has programs, such as conservation compliance, to encourage the adoption of soil management practices on highly erodible lands, which can reduce soil sedimentation and chemical runoff caused by erosion (see chapter 6.4, *Conservation Compliance*; Fuglie, 1995; and Fuglie and Klotz, 1994).

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Developing a Green Technology - An Example

The Minnesota Agri-Power (MAP) project is developing a power plant that uses biomass from alfalfa stems to generate electricity. The project, coordinated by the Center for Alternative Plant and Animal Products at the University of Minnesota, also includes the production of an alfalfa leaf-meal coproduct.

The MAP project was borne out of two Federal environmental goals: the Department of Energy's (DOE) efforts to reduce the level of emissions associated with electricity production from fossil fuels, thereby positively affecting global climate change; and USDA's efforts to increase farm adoption of environmentally beneficial crop rotations and to revitalize rural economies by finding new markets for agricultural products. Accordingly, USDA and DOE began the "Biomass Power for Rural Development Project" to cost-share renewable energy technology demonstration and commercializations. The development of this technology was aided by regulatory statutes. In 1994, Minnesota passed legislation requiring power companies to derive a certain portion of their total electrical energy from farm-grown biomass. This created a market for the electricity provided by MAP.

Many levels of research (basic, applied, and developmental) went into this effort. DOE basic research raised concerns about changing global climate and indicated that biomass energy could have atmospheric benefits. Agricultural research into the properties of alfalfa plants gave scientists the knowledge that such crops can be used to produce energy. Additional agricultural work (more applied in nature) has demonstrated that rotations with alfalfa can offer significant environmental benefits—for example, improved nitrogen balance and less nitrogen runoff, reduced soil erosion, and wildlife benefits.

The Minnesota Agri-Power project team had already completed significant research and feasibility study before receiving the Biomass Power for Rural Development grant. A team was assembled that included the University of Minnesota, the Minnesota Valley Alfalfa Producers (a farmer cooperative), USDA-ARS and Natural Resource Conservation Service, the State Departments of Natural Resources and Agriculture, local officials, Westinghouse Electrical Corp., and other private power, engineering and financing companies. As a land grant university, the University of Minnesota could draw on agricultural engineers, applied economists, soil scientists, agronomists, and plant geneticists, as well as agricultural experiment station resources and the Extension Service. This team, coordinated by the Center for Alternative Plant and Animal Products, will continue to work on the next phase of development.

Throughout, MAP's goal has been to develop environmentally and economically sustainable agriculturally based power. Economists have provided analysis on expected market conditions, economic yields, and the effects of farm programs. The project developers also wanted to ensure farmer participation. Early in the first feasibility study, the Department of Adult Agricultural Education conducted a series of focus groups with farmers to solicit farmer input in the planning and assessment process.

The technology transfer mechanisms used in this project are relatively new. Since DOE and USDA want to commercialize the technology, private sector participation was a requirement for receiving a grant. One strength of cooperative research agreements is that they bring together different expertise (public, private, and academic) to achieve interdisciplinary objectives. The use of newly available collaborations, as in this project, shows great promise for continuing the past successes of the agricultural research establishment in the area of environmental protection.

Source: USDA, ERS, based mostly on Center for Alternative Plant and Animal Products, 1994.

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Recent ERS Reports on Research and Technology Issues

Agricultural Research and Development: Public and Private Investments Under Alternative Markets and Institutions, AER-735, July 1996 (Keith Fuglie, Nicole Ballenger, Kelly Day, Cassandra Klotz, Michael Ollinger, John Reilly, Utpal Vasavada, and Jet Yee). This report discusses the history of agricultural research and research policy, and reviews the high rate of return on public agricultural research. Public funding of agricultural research, which has been relatively stagnant, is unlikely to increase. Private agricultural research has been affected by stronger intellectual property rights and public-private cooperative research mechanisms.

"Productivity: Agriculture's Engine of Growth," *Agricultural Outlook*, May 1996 (Eldon Ball and Richard Nehring). The article reports agricultural productivity growth statistics. The concepts behind productivity measurement are described, as well as factors influencing growth rate changes. The article also explains why the new indexing procedures are more accurate and easily interpreted.

Private-Sector Agricultural Research Expenditures in the United States, 1960-92, ERS Staff Paper No. AGES-9525, Oct. 1995 (Cassandra Klotz, Keith Fuglie, and Carl Pray). Private agricultural research has grown substantially, especially among chemical and biological technologies. However, data on private agricultural research spending are incomplete and fragmented.

Regulation, Innovation, and Market Structre in the U.S. Pesticide Industry, AER-719, June 1995 (Michael Ollinger and Jorge Fernandez-Cornejo). Pesticide regulation encourages the development of "less toxic" pesticides, but also discourages new chemical pesticides and affects minor crop-use pesticides. Various other impacts of pesticide regulation are discussed.

New Crop Varieties, AREI Update No. 14, 1995 (Keith Fuglie, Cassandra Klotz, and Mohinder Gill). This update of crop varieties indicates that expanded legal protection for new crop varieties has stimulated private-sector breeding efforts. Plant patents are the most popular intellectual property rights, followed by Plant Variety Protection Certificates and Utility Patents.

Agricultural Research, AREI Update No. 5, revised, 1995 (Keith Fuglie, Kelly Day, George Frisvold, and Cassandra Klotz). This update presents data showing that private research now exceeds public research, and also grew at a faster rate in 1992. The report also presents funding data for all 50 States' agricultural experiment stations by source, and gives the flow of research funds between Federal, State, and private sectors for 1992.

The Value and Role of Public Investment in Agricultural Research, ERS Staff Paper No. AGES-9510, May 1995 (Keith Fuglie, Nicole Ballenger, Kelly Day, Cassandra Klotz, John Reilly, and Jet Yee). This document outlines, in graphs and figures, ERS findings about funding trends, rates of return, and public-private collaboration in agricultural research.

Private and Public Financing of Agricultural Research and Development, AIB-664-69, Feb. 1994 (George Frisvold, Jet Yee, and Kelly Day). The U.S. agricultural research system is facing increased demands, including increased research spending by competing countries and regions. Policy alternatives are discussed by which public institutions can coordinate research efforts with the private sector.

Adoption of Cost Management Strategies Under Varying Environmental Conditions, TB-1827, Dec. 1993 (Margriet Caswell and Robbin Shoemaker). This report provides a technical analysis of several policy instruments designed to encourage the adoption of chemical-reducing pest management strategies.

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